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FORECASTING MARCH TEMPERATURE AND RAINFALL FOR ENGLAND AND WALES

By R. MURRAY

Summary. The large-scale monthly mean circulation patterns over the north-east Atlantic and western Europe typical of particular classes of temperature and rainfall over England and Wales are discussed with the help of monthly mean surface pressure anomaly maps. Several forecasting rules, mostly based on *PSCM* indices, are presented. The main rules are as follows :

(i) Northerly cyclonic Februarys are generally followed by cold Marches, whereas southerly cyclonic Februarys are followed by warm Marches.
(ii) Blocked anticyclonic winters are mostly followed by wet Marches (i.e. antipersistence in rainfall) and progressive anticyclonic by dry Marches (i.e. persistence in rainfall).
(iii) Blocked northerly types in the January to February periods are usually followed by wet Marches and progressive northerly by dry Marches.

Refinements of the forecasting rules and their relation to sea surface temperature anomalies are discussed.

Introduction. In British climatology it is conventional to regard March as the first month of spring but it could equally well be taken as the last month of winter. Certainly many winters end before March whilst others are prolonged well into March or even into April, as in 1970. September has also a somewhat equivocal position in relation to summer and autumn: September can often be regarded as a summer month (e.g. 1959) even though it is conventionally the first month of autumn.

The purpose of this paper is to present some synoptic-statistical relationships concerning March and to indicate how the mean monthly temperature and rainfall in March can be predicted by simple objective methods.

It is appropriate to mention here that the *PSCM* indices, which are employed for objective specification of large-scale circulation anomalies and in long-range forecasting in the British Meteorological Office, were originally put forward by Murray and Lewis.[1] These indices were recently discussed by Murray[2] and by Murray and Benwell[3] after having been recomputed to take account of the revision by Lamb[4] of his catalogue of daily synoptic types over the British Isles.

In the following pages mean temperature will generally refer to mean monthly temperature over central England — see Manley.[5] Central England mean temperature is representative of mean temperature over England and Wales. In point of fact, in March the spatial correlation of mean monthly temperature falls off quite slowly with increasing distance from central

England, being about 0·9 near the Scottish border, Cornwall and the Low Countries and greater than 0·8 in Scotland, Ireland, northern France and western Germany.

As is normal practice in long-range forecasting, mean temperatures are employed in their quintile form. In other words the ranked temperature distribution is divided into five equal classes and the coldest 20 per cent are called quintile 1 or T_1, the next coldest 20 per cent are quintile 2 or T_2 and so on. Two or more quintiles may be referred to as T_{12}, etc. Quintile boundary values for temperature 1873–1963 are given by Murray,[6] and for *PSCM* indices 1869–1968 by Murray and Benwell.[3] Rainfall is usually classified into three groups and the driest is tercile 1 or R^1. Tercile boundary values for rainfall 1866–1965 are given by Murray.[7] In general the positive or high values of a measured quantity are placed in the quintile or tercile with the highest number. Pressure anomalies are measured as departures from the 1873–1968 mean. The various associations given in this paper are based on sets of data for temperature, rainfall, pressure and *PSCM* indices, whose periods overlap to some extent and give a resultant period of about 100 years.

Unless otherwise stated, the term 'significant' is to be regarded as meaning statistically significant at the 5 per cent level or better, and 'highly significant' as statistically significant at the 1 per cent level or better in chi-square or *t*-tests.

Circulation, temperature and rainfall in March. It is useful to have a picture of the broad-scale circulation which is typically associated with specific types of temperature and rainfall as indicated by percentiles. Figure 1*(a)* depicts the mean pressure anomaly pattern associated with very cold (quintile 1 or T_1) Marches. In this composite map mean pressure is significantly above average over a large region centred roughly on Greenland and significantly below average over an extensive belt in middle latitudes of Europe and in slightly lower latitudes of the North Atlantic. A strong north-east anomaly of flow is shown over the north-east Atlantic and the British Isles. The composite map for T_2 Marches (not shown) is much weaker than Figure 1*(a)*. The T_2 map has a significant positive area (i.e. above average pressure) over the Kara Sea and a significant negative area from Algeria to the Black Sea with a rather weak north-east anomaly of flow over the British Isles, but no significant area over Greenland, North America and the North Pacific.

Figure 1*(b)* shows the mean anomalous circulation associated with very warm (T_5) Marches. There is a strong south-west anomaly of flow over the British Isles. The mean pressure anomaly pattern is practically the reverse of that shown in Figure 1*(a)*. The T_4 map (not shown) is much weaker than Figure 1*(b)*; it has a significant positive area over central and east Europe and a significant negative area near south Greenland but no significant anomalies over Asia, the North Pacific and North America.

It is interesting that the composite map for T_3 Marches (not shown) has a very weak pattern over western Europe and indeed no significant anomalies from 60°W eastwards to 140°E. However, pressure is significantly above average over the Aleutians and significantly below average near the south of Hudson Bay.

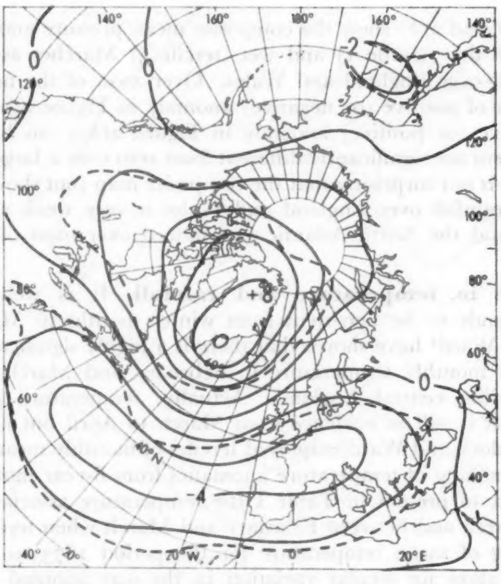

FIGURE 1(*a*)—MEAN PRESSURE ANOMALY PATTERN ASSOCIATED WITH VERY COLD (QUINTILE 1) MARCHES OVER CENTRAL ENGLAND

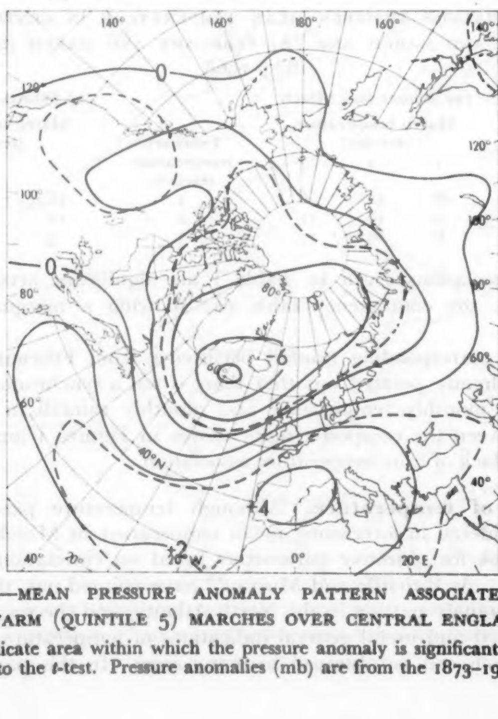

FIGURE 1(*b*)—MEAN PRESSURE ANOMALY PATTERN ASSOCIATED WITH VERY WARM (QUINTILE 5) MARCHES OVER CENTRAL ENGLAND

Broken lines indicate area within which the pressure anomaly is significant at the 5 per cent level according to the *t*-test. Pressure anomalies (mb) are from the 1873–1968 mean pressure.

Figures 2*(a)* and 2*(b)* show the composite mean pressure anomaly patterns associated with dry (tercile 1) and wet (tercile 3) Marches as given by the general rainfall over England and Wales. Over most of the northern hemisphere an area of positive (or negative) anomaly in Figure 2*(a)* becomes an area of negative (or positive) anomaly in Figure 2*(b)*; on both maps the anomaly patterns are significantly different from zero over a large area centred on Ireland. It is not surprising that the composite map (not shown) associated with average rainfall over England and Wales is very weak and featureless over Europe and the North Atlantic and indeed over most of the northern hemisphere.

Persistence in temperature and rainfall. It is well known that temperature tends to be persistent from winter months to March. Indeed Craddock and Ward[8] have shown that there is a highly significant association between mean monthly temperature in February and March over most of Europe, including central England. Actually, temperature persistence in central England is still in evidence from March to April but not from April to May. Craddock and Ward employed terciles of monthly mean temperature based on the ranking of temperature anomalies from 8-year moving averages. It is of interest to present in Table I the temperature associations between winter and March and between February and March when terciles are based on the ranking of mean temperature for the period 1873 to 1963 without attempting to allow for secular variation in the way adopted by Craddock and Ward.

TABLE I—ASSOCIATIONS BETWEEN MEAN TEMPERATURE IN CENTRAL ENGLAND IN *(a)* WINTER AND MARCH AND *(b)* FEBRUARY AND MARCH IN THE PERIOD 1873–1968

	(a) Winter and March				*(b)* February and March		
	March temperature (terciles)				March temperature (terciles)		
Winter temperature (terciles)	1	2	3	February temperature terciles)	1	2	3
1	18	12	6	1	16	14	5
2	9	10	11	2	12	8	12
3	6	9	17	3	5	9	17

The two associations given in Table I are significant according to the chi-square test, the contingency table *(b)* showing a marginally stronger relationship.

There is no corresponding rainfall persistence from February to March. Murray[9] has already pointed out that there is not a synchronous association between mean monthly temperature and monthly rainfall in March; the differences between the composite maps shown in Figures 1 and 2 also tend to confirm the lack of rain/temperature association.

Prediction of temperature. Although temperature persistence must always be considered in forecasting mean temperature in March, it is clearly desirable to look for objective parameters based on circulation or on other physical factors. As Ratcliffe and Murray[10] have pointed out, the sea surface temperature anomaly pattern in the North Atlantic and the mean circulation are closely linked and useful general indications of temperature over western Europe in March can be obtained in many cases. In this paper, however,

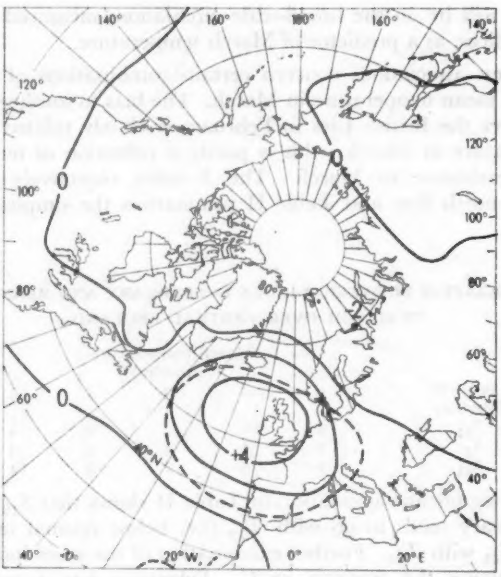

FIGURE 2(*a*)—MEAN PRESSURE ANOMALY PATTERN ASSOCIATED WITH DRY (TERCILE 1) MARCHES OVER ENGLAND AND WALES

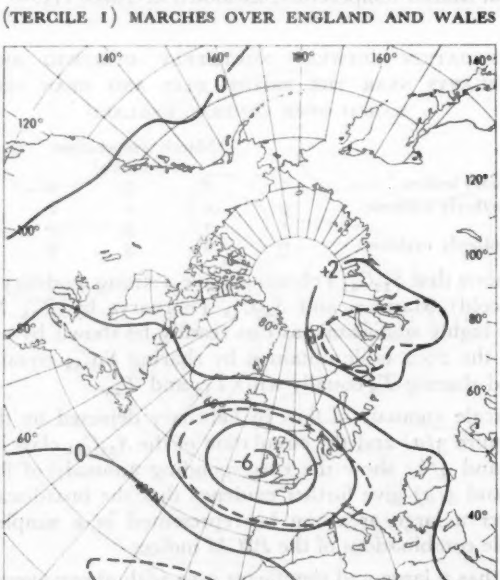

FIGURE 2(*b*)—MEAN PRESSURE ANOMALY PATTERN ASSOCIATED WITH WET (TERCILE 3) MARCHES OVER ENGLAND AND WALES

See note at foot of Figure 1(*b*).

the emphasis will be on the broad-scale circulation, measured objectively by the *PSCM* indices, as a predictor of March temperature.

The strongest associations concern certain combinations of the indices in February and mean temperature in March. The bias to southerly or northerly circulation over the British Isles in February is closely related to subsequent mean temperature in March; this is partly a reflection of temperature and circulation persistence to March. The S index objectively measures any bias in south–north flow and Table II summarizes the simplest type of relationship.

TABLE II—ASSOCIATION BETWEEN S INDEX IN FEBRUARY AND MEAN TEMPERATURE IN MARCH OVER CENTRAL ENGLAND

S index in February	March temperature (quintiles) 1	2	3	4	5
S_{12}	15	16	7	6	4
S_3	3	4	4	5	3
S_{45}	3	5	7	12	14

The highly significant association in Table II shows that S_{12} (i.e. northerly bias) in February tends to go with T_{12} (i.e. below normal temperature) in March, and S_{45} with T_{45}. Further examination of the cases indicates that the sub-class involving the cyclonic or C_{45} Februarys has a more significant association with March temperature, as shown in Table III.

TABLE III—ASSOCIATION BETWEEN NORTHERLY CYCLONIC AND SOUTHERLY CYCLONIC FEBRUARYS NEAR THE BRITISH ISLES AND MEAN TEMPERATURE IN MARCH OVER CENTRAL ENGLAND

February indices	March temperature (quintiles) 1	2	3	4	5
$S_{12}C_{45}$ (northerly cyclonic)	9	10	1	2	0
S_3C_{45}	1	1	3	0	2
$S_{45}C_{45}$ (southerly cyclonic)	0	2	3	4	5

Table III shows that $S_{12}C_{45}$ Februarys have a strong tendency to be followed by T_{12} (i.e. cold) Marches and $S_{45}C_{45}$ Februarys by T_{45} Marches. The relationship is highly significant, as can readily be shown by applying a chi-square test to the 2×2 table obtained by sharing S_3C_{45} equally with $S_{12}C_{45}$ and $S_{45}C_{45}$ and sharing T_3 equally with T_{12} and T_{45}.

The broad-scale anomaly of flow in February depicted by the $S_{12}C_{45}$ class is shown in Figure 3*(a)* and the circulation of the $S_{45}C_{45}$ class in Figure 4*(a)*. Figures 3*(b)* and 4*(b)* show the corresponding anomaly of flow in March. Figures 3*(a)* and 4*(a)* give further evidence that the broad-scale anomaly of circulation over a large area can be represented in a simple, quantitative way by suitable combinations of the *PSCM* indices.

Figure 3*(b)* has a large and significant area with above average pressure in high latitudes and a corresponding area with below average pressure over middle to low latitudes in Europe and the North Atlantic; the blocking pattern is on a huge scale. The circulation change from February to March shown in Figures 3*(a)* and *(b)* shows a build-up of pressure in the Arctic

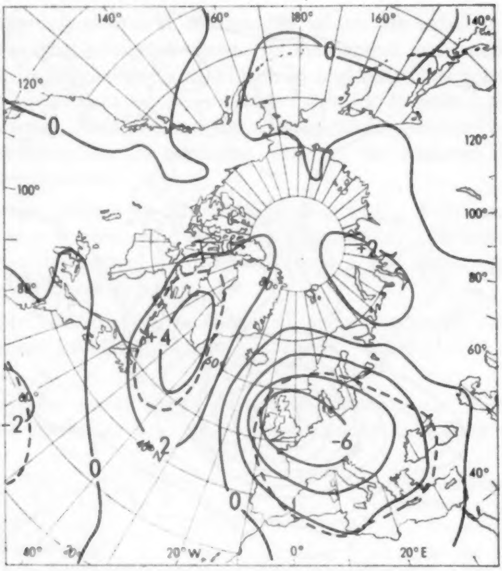

FIGURE 3(*a*)—MEAN PRESSURE ANOMALY PATTERN IN FEBRUARY ASSOCIATED WITH THE $S_{12}C_{45}$ (NORTHERLY CYCLONIC) CLASS OF FEBRUARY

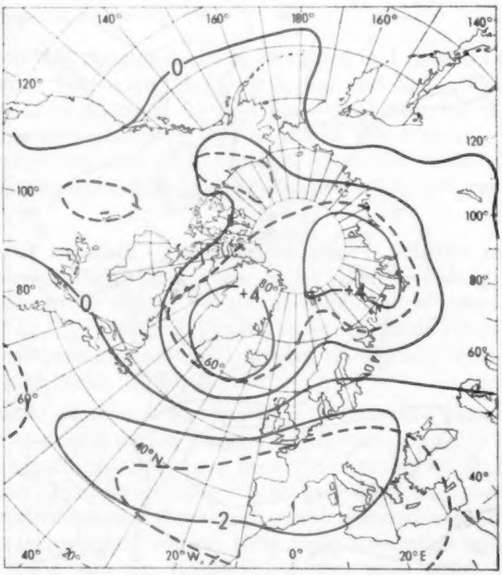

FIGURE 3(*b*)—MEAN PRESSURE ANOMALY PATTERN IN MARCH FOLLOWING THE $S_{12}C_{45}$ (NORTHERLY CYCLONIC) CLASS OF FEBRUARY

See note at foot of Figure 1(*b*).

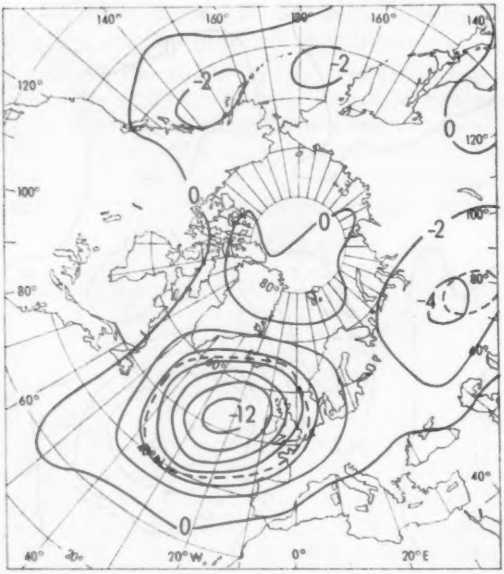

FIGURE $4(a)$—MEAN PRESSURE ANOMALY PATTERN IN FEBRUARY ASSOCIATED WITH THE $S_{45}C_{45}$ (SOUTHERLY CYCLONIC) CLASS OF FEBRUARY

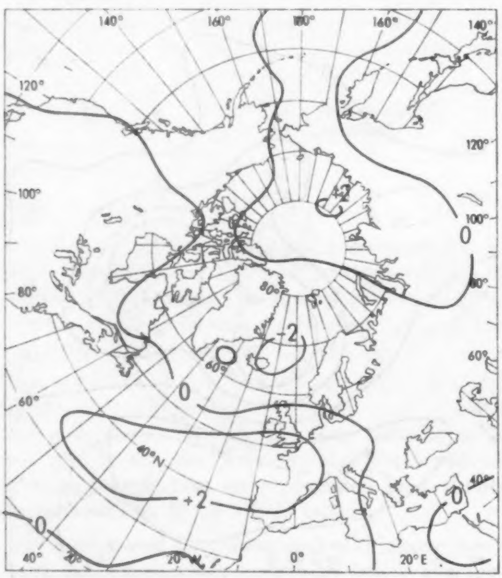

FIGURE $4(b)$—MEAN PRESSURE ANOMALY PATTERN IN MARCH FOLLOWING THE $S_{45}C_{45}$ (SOUTHERLY CYCLONIC) CLASS OF FEBRUARY

See note at foot of Figure 1*(b)*.

and some weakening and drift southwards of the pre-existing area of below average pressure over western Europe. In the normal year there is a build-up of pressure between February and March in high latitudes centred on Greenland (+4 mb approximately over south Greenland) and a fall of pressure over North America, Asia and southern Europe; the pressure changes following $S_{12}C_{45}$ Februarys are in the same sense as the seasonal changes in the Atlantic/European sector.

The circulation pattern in March following $S_{45}C_{45}$ Februarys is shown in Figure 4*(b)* and it is nearly the reverse of Figure 3*(b)*. However, the positive area over and to the west of south-west Europe is just about significant at the 5 per cent level near north Spain.

The predictive relationships in Tables II and III may be supplemented by further associations involving circulation types in Table IV.

TABLE IV—VARIOUS ASSOCIATIONS BETWEEN CIRCULATION TYPES NEAR THE BRITISH ISLES IN FEBRUARY AND MEAN TEMPERATURE IN MARCH OVER CENTRAL ENGLAND

	March temperature (quintiles)				
February indices	1	2	3	4	5
$P_{12}S_{12}$ (blocked northerly)	7	6	5	2	0
$P_{12}S_{12}$ or $S_{12}C_{45}$ (5 common years counted once)	13	14	6	4	0
$P_{45}S_{45}$ (progressive southerly)	1	2	3	2	8
$P_{45}S_{45}$ or $S_{45}C_{45}$ (6 common years counted once)	1	3	4	6	10

It is of interest that none of the rules contained in Tables III and IV involve C_{12} (anticyclonic) Februarys. Actually $S_{12}C_{12}$ and $S_{45}C_{12}$ Februarys have a weak tendency to be followed by cold and warm Marches respectively, but the relationships are apparently determined by the S index. Indeed C_{12} by itself (i.e. whatever the value of S) shows no predictive value, since the March temperature distribution following C_{12} Februarys is $8T_1$, $9T_2$, $10T_3$, $11T_4$, $6T_5$.

Prediction of rainfall. The poor correlation between monthly rainfall and temperature in March means that 'rules' used for prediction of temperature are unlikely to be equally helpful in rainfall forecasting. For instance, the $S_{12}C_{45}$ and $S_{45}C_{45}$ types of February, shown in Table III to be very useful in forecasting temperature in March, are not satisfactory predictors of rainfall over England and Wales in March.

The broad-scale circulation during winter (December+January+February) and over the two-month period January+February appear to be much better indicators of March rainfall than does the circulation in February. P_{12} (blocked) winters tend to be followed by wet Marches ($10R_1$, $14R_2$, $23R_3$) but P_{45} (progressive) winters show only a weak association ($19R_1$, $13R_2$, $12R_3$). Similarly C_{12} (anticyclonic) winters show some association with wet Marches ($12R_1$, $14R_2$, $18R_3$), but C_{45} (cyclonic) winters show none. S_{12} (northerly) and S_{45} (southerly) winters have no relationship with rainfall in March. For the C_{12} winters subdivided according to their progressiveness the association shown in Table V is highly significant.

TABLE V—ASSOCIATION BETWEEN BLOCKED ANTICYCLONIC AND PROGRESSIVE ANTICYCLONIC WINTERS NEAR THE BRITISH ISLES AND RAINFALL IN MARCH OVER ENGLAND AND WALES

	March rainfall (terciles)		
Winter indices	1	2	3
$P_{12}C_{12}$ (blocked anticyclonic)	2	5	14
P_3C_{12}	2	5	2
$P_{45}C_{12}$ (progressive anticyclonic)	8	4	2

Clearly, blocked anticyclonic winters are mostly followed by wet Marches, whereas progressive anticyclonic winters are biased towards dry Marches. The composite mean pressure anomaly maps associated with the $P_{12}C_{12}$ winters and the following Marches are shown in Figures 5*(a)* and *(b)* respectively. Figure 5*(a)* shows a large-scale blocking pattern near western Europe, typical of the $P_{12}C_{12}$ type winter. In March, following $P_{12}C_{12}$ winters, there is evidently a general fall of pressure over the eastern Atlantic and the British Isles and it is not surprising that above average rainfall typically occurs in March as indicated in Table V. Incidentally, the composite map (not shown) representing the $P_{45}C_{12}$ winters of Table V has positive pressure anomalies over south and central Europe, with a significant area (>3 mb) over France, and negative pressure anomalies in higher latitudes with a significant area (<-4 mb) near and over the Barents Sea. The composite map (not shown) for the Marches following $P_{45}C_{12}$ winters has a significant positive anomaly centre (>4 mb) between the Azores and Ireland, which implies a retrogression of the pre-existing centre of positive anomaly over France in the winter. Moreover, the composite map for March shows a north-west anomaly of flow and pressure slightly above average over the British Isles.

From Table V it is seen that two dry Marches followed the $P_{12}C_{12}$ winters. It is of interest that these dry Marches are eliminated from the statistics if a further proviso is made that there should be a northerly component in the anomaly of flow over the British Isles (i.e. the anticyclonic block shifted a little west of the mean position shown in Figure 5*(a)*). The $P_{12}S_{12}C_{12}$ winters were in fact associated with seven wet, four average and no dry Marches.

Examination of the circulation indices for the two-month period January to February suggested that $P_{12}S_{12}$ (blocked northerly) and $P_{45}S_{12}$ (progressive northerly) types were useful indicators. Actually $P_{12}C_{12}$ and $P_{45}C_{12}$ types give similar, but weaker, indications to those given in Table V. However, the best associations are presented in Table VI.

TABLE VI—ASSOCIATION BETWEEN BLOCKED NORTHERLY AND PROGRESSIVE NORTHERLY TYPES IN JANUARY TO FEBRUARY NEAR THE BRITISH ISLES AND RAINFALL IN MARCH OVER ENGLAND AND WALES

	March rainfall (terciles)		
January to February indices	1	2	3
$P_{12}S_{12}$ (blocked northerly)	2	7	9
P_3S_{12}	4	3	3
$P_{45}S_{12}$ (progressive northerly)	12	2	1

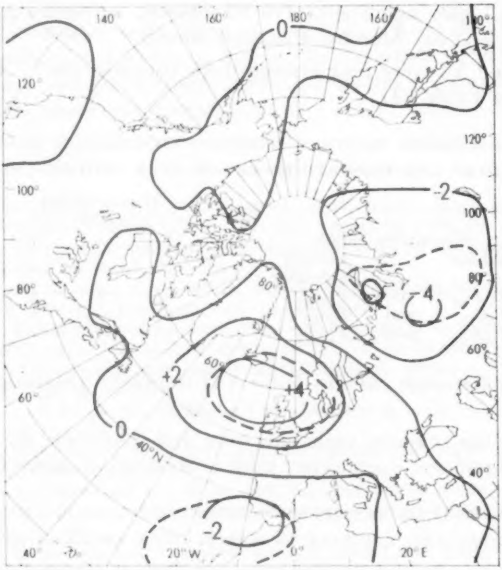

FIGURE 5(*a*)—MEAN PRESSURE ANOMALY PATTERN IN WINTER ASSOCIATED WITH THE $P_{12}C_{12}$ (BLOCKED ANTICYCLONIC) CLASS OF WINTER

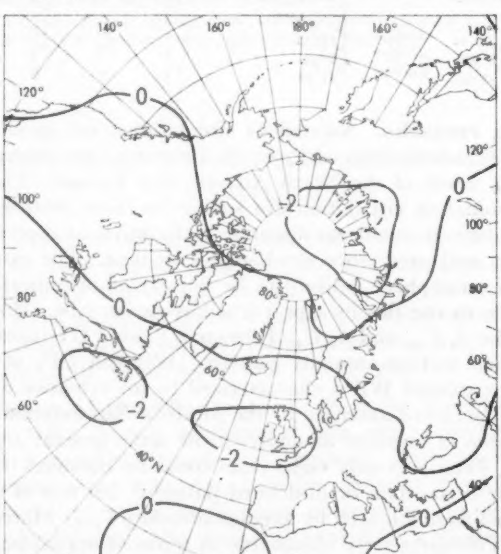

FIGURE 5(*b*)—MEAN PRESSURE ANOMALY PATTERN IN MARCH FOLLOWING THE $P_{12}C_{12}$ (BLOCKED ANTICYCLONIC) CLASS OF WINTER

See note at foot of Figure 1(*b*).

Table VI is highly significant. The relationship between $P_{45}S_{12}$ in January plus February and dry Marches is notably strong.

Tables V and VI were next examined for common years. The results are summarized in Table VII.

TABLE VII—ASSOCIATION BETWEEN SPECIFIED CIRCULATION CLASSES NEAR THE BRITISH ISLES AND RAINFALL IN MARCH OVER ENGLAND AND WALES

Circulation indices			March rainfall (terciles)		
Winter		January to February	1	2	3
$P_{12}C_{12}$	and	$P_{12}S_{12}$	0	2	5
P_3C_{12}	and	P_3S_{12}	1	0	1
$P_{45}C_{12}$	and	$P_{45}S_{12}$	5	0	0

There are not enough cases in Table VII to permit a statistical significance test.

By counting the common years only once and combining the Tables V and VI, a highly significant contingency table is obtained as shown in Table VIII.

TABLE VIII—ASSOCIATION BETWEEN SPECIFIED CIRCULATION CLASSES NEAR THE BRITISH ISLES AND RAINFALL IN MARCH OVER ENGLAND AND WALES

Circulation indices			March rainfall (terciles)		
Winter		January to February	1	2	3
$P_{12}C_{12}$	and/or	$P_{12}S_{12}$	4	10	18
P_3C_{12}	and/or	P_3S_{12}	5	8	4
$P_{45}C_{12}$	and/or	$P_{45}S_{12}$	15	6	3

Concluding remarks. Anomalous circulation types given by particular combinations of indices, such as $P_{12}C_{45}$ in February, are generally on a large scale, affecting much of the North Atlantic and Europe. These large-scale patterns of anomalous circulation are similar to those recently discussed by Sawyer,[11] but he was unable to disentangle the physical processes relating to their formation and persistence or change with time. The exchange of heat from ocean to atmosphere is likely to be one factor of importance, but it is not yet possible to use this in a practical forecasting rule. However, it is of interest that the $S_{12}C_{45}$ and $S_{45}C_{45}$ Februarys (Table III) were examined in terms of the sea surface anomaly patterns (WP and CP) of Ratcliffe and Murray.[10] The pattern WP is characterized by an extensive area of positive sea surface temperature anomaly to the south of Newfoundland and CP by an extensive area of negative anomaly in the same general area. Of the 22 cases of $S_{12}C_{45}$ Februarys only eight years could be classified (the other years had inadequate or no data or ill-defined patterns) but five of these were the WP type and all were followed by average or cold (T_{123}) Marches. Similarly the 14 $S_{45}C_{45}$ Februarys were classifiable in terms of sea surface temperature patterns in only seven cases; these were all CP type and were followed by average or warm (T_{345}) Marches. There is evidently a link here. However, it is also clear that for practical forecasting, at least in this instance, the *PSCM* indices can be applied on many more occasions. A similar conclusion was

arrived at after looking at the sea surface temperature patterns in January and February associated with some of the *PSCM* rules for predicting the rainfall over England and Wales in March. In this paper the simple objective procedures which are given enable useful prediction of March temperature and rainfall to be made on many occasions.

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FIFTY YEARS AT LERWICK OBSERVATORY

By J. B. TYLDESLEY

Introduction. Lerwick Observatory celebrates its fiftieth anniversary on 7 June 1971. In 1950 Harper[1] produced an excellent account of the work of the Observatory up to that time. In this article some historical information on the setting up of the Observatory is given, with brief reference to the work of the first 30 years and a somewhat fuller description of developments since 1950. Plate I shows the Observatory as it was in 1965.

The foundation of the Observatory. After the First World War, the Meteorological Office had a development plan which included setting up meteorological stations in Orkney and Shetland. In 1919 the Norwegian Government asked other countries, including Britain, to set up stations in northerly latitudes to make geophysical observations in connection with Amundsen's polar voyage. Also there was a need for a magnetic observatory in the far north of the British Isles. Not only was Kew increasingly troubled with artificial disturbance but records from Eskdalemuir Observatory (set up in 1908) had shown that the day-to-day magnetic variations there were about twice as great as at Kew. In terms of latitude, approximately half of the

British Isles is north of Eskdalemuir, and moreover this half is on the southern edge of the auroral zone, so that on all counts, further increase of magnetic variation was expected in the far north.

These three factors — meteorological observations, help for Amundsen, and magnetic observations — appear (with different emphasis) in all the correspondence on setting up the Observatory. In February 1920 the Director, Sir George Simpson, wrote to Dr Charles Chree, his Superintendent at Kew, about the project; and Chree immediately got in touch with Dr Crichton Mitchell at Eskdalemuir and arranged to include provision for a station in Shetland in the estimates for the following year.

Thereafter things moved rapidly. In April the Director set up a powerful committee consisting of Dr Chree, Mr Lempfert, Lieutenant-Colonel Gold, Dr Crichton Mitchell, Mr Richardson and Mr Corless. Mr Watson Watt was to advise on radio communication. The committee considered the work to be done and various sites including places in the north isles of Yell and Unst, and on the north mainland, as well as near Lerwick. Crichton Mitchell was sent to Shetland to investigate, and came down in favour of the old Admiralty wireless station on the outskirts of Lerwick, largely because there were existing houses which could be used both as offices and for accommodating staff. He submitted a most comprehensive report on all that needed to be done, both scientifically and domestically. On the accommodation, he said : 'The houses are very small. The largest room in No. 1' (which was to be the Superintendent's house) 'is only about 10 feet square. They have been constructed on the lines of artisans cheap houses and are not of such a character as the men to be posted to the Observatory can have been accustomed.' There was an element of special pleading in this, for Crichton Mitchell went on to argue the case for charging low rents for the houses, in order to make a spell at such an 'outlandish place' reasonably attractive to the staff.

In November 1920 the Director visited Shetland himself, and in December he sought and received Treasury permission to go ahead. Times were hard, and he was expected to run the Observatory without receiving any extra staff or funds. The proposed station in Orkney was forgone, largely because the Navy no longer required it, and that helped with staffing. Equipment was mostly to be borrowed from the other observatories and refurbished. However a non-magnetic hut for the absolute instruments was required, also a magnetograph house of non-magnetic construction. Dr Chree was much exercised by the magnetograph house. The continuously recording magnetic instruments of the day were seriously affected by changing temperatures, which had to be reduced to a minimum. At Eskdalemuir the problem had been solved by making a cavern in the hillside, but funds were not available to do this at Lerwick. Two designs were considered. One was for a hut within a hut, the outer of three thicknesses of concrete blocks, with a six-inch air space and a second six-inch space filled with slag wool, and triple glazing. The inner hut, supported on piers, would have been a double skin of timber and plaster, again with slag-wool filling. The other, which was eventually adopted, was for a monolithic concrete structure with a half-cylindrical top. The object was to reduce outside diurnal variations of 5 degC to 0·05 degC inside. Dr Chree wrote to the Director at length about the design, deploying his knowledge of non-steady-state heat-conduction theory, and walls up to

three feet thick were contemplated. It is interesting that Chree's lengthy notes were in his own hand, and went to Dr Simpson personally at South Kensington.

The Observatory was opened on 7 June 1921 by Dr Crichton Mitchell, who stayed until 13 June. He left Mr J. Crichton as officer-in-charge, with a staff of two probationers, a caretaker, and a wireless operator. There is no record of any celebrations, and all the evidence is that it was very much a working visit to get the Observatory going. While at Lerwick, Crichton Mitchell added his share to the weight of calculations on the magnetograph house, bemoaning the absence of tables of Bessel functions in Shetland. He favoured the use of coke breeze to give an insulating concrete, but tests at Eskdalemuir showed that the local material was strongly magnetic. In the end shingle was used as aggregate. Work began in 1921 and finished in the spring of 1922. Plate II shows the house as it is today, and Plate III, taken while the work was in progress, suggests that it taxed local resources severely. In the background of the latter photograph, the Admiralty wireless masts and the original houses can be seen.

The magnetic work. The photographically recording magnetographs are described by Harper.[1] Although fires were kept burning continuously in the house for the first six months, damp was always a problem, and continued to be so for many years, until it was possible to install electric heaters in 1946. In 1926 a bizarre method of drying, suggested by the Director on a visit, was tried. A canvas bag filled with calcium chloride was hung from the ceiling and a bucket placed beneath to catch the drippings. Temperature effects were also troublesome. The variations in the house were never as small as the calculations concerning the 2½-foot walls had indicated, probably because it was necessary to ventilate the house continuously with outside air to reduce condensation. Despite all these difficulties, reliability improved gradually over the years, and the house is still in use. Plate IV shows the scene when the lights were switched on briefly in July 1965. The quick-run La Cour magnetograph is nearest the camera, with the variometers on the left and recorders on the right. The supplementary (storm) magnetograph is beyond. The wiring has an improvised look, and various black screens intended to eliminate stray light may be seen. The picture emphasizes the difficulty of doing this taxing technical work in almost complete darkness.

The magnetographs are standardized by absolute instruments housed in a separate hut. The Kew magnetometer has been used for declination since 1922, but all the other instruments have been superseded. The biggest change was the introduction of the proton vector magnetometer in 1964. In this instrument the frequency of precession of protons in the earth's field is measured electronically. The proton sample consists of a plastic bottle of water around which exciting and sensing coils are wound. Large Helmholtz coils surround the sample, and remove in turn the unwanted components of the earth's field. Plate V shows the sensor and coils, and beside it may be seen the Kew magnetometer. An advantage of the proton instruments, over their predecessors incorporating 'permanent' magnets, is that the magnetic moment of the proton is the same at all places and times. Thus inter-observatory comparisons are no longer required; a fact which is in some ways regretted by the staffs of these isolated stations.

In recent years modern instruments have also been tried as variometers. In 1961 a digitally recording version of the proton magnetometer was installed, and also a rubidium vapour magnetometer, which makes use of the Zeeman splitting of the electronic energy levels of that element. Experiments with the latter have continued to the present. In 1965 fluxgate magnetometers were installed. Up to now, however, none of these instruments has proved sufficiently reliable and sufficiently stable to be incorporated in the basic observatory routine, and the 40-year-old La Cour design still holds sway.

The original purposes of the magnetic observations were to assist navigation, and for the reduction of magnetic surveys made for geological purposes. These functions still continue, and recently the latter has become important again as the search for oil and natural gas spreads into the northern North Sea. The day-to-day variations of the magnetic field are due to electric currents in the earth's upper atmosphere, and the Lerwick readings, along with those of many other observatories, have helped to elucidate these currents and their variations. This work also has received added stimulus in recent years. Whereas formerly the electric currents could only be deduced indirectly from ground observations, rockets and satellites can now penetrate the parts of the atmosphere concerned. Because these pass rapidly through the regions of interest, the ground-based magnetic observations have renewed importance in forming a framework for the satellite data.

In 1965, national responsibility for geomagnetism was vested in the Institute of Geological Sciences of the Natural Environment Research Council. The Meteorological Office continued to carry out the geomagnetic work at Lerwick as an agent of NERC until 1969, when NERC sent two of their own staff to the Observatory.

Aurora. This subject is mentioned next, because of its close connection with the magnetic work. The aurora is caused by electrical excitation of the upper atmosphere by energetic protons and electrons flowing from the sun. Naturally the electric currents in the magnetosphere are also affected, so aurora is often accompanied by notable magnetic disturbance. Lerwick is on the southern edge of the auroral zone and therefore well placed to observe these connections.

It had from the first been intended to observe aurora in Shetland. Crichton Mitchell's first report on the proposed stations puts auroral parallax-photography at the head of the list of possible observations. He envisaged a second station at Hillswick, about 42 km north-north-west of the Observatory, with a staff of two throughout the winter. No doubt he had Störmer's pioneer work on the determination of the height of the aurora in mind, because the man in charge was to be sent to Norway for training, and two special cameras were to be bought there. Although a nightly auroral watch in winter was soon instituted, it was several years before photography could be begun. In 1928 a single Krogness camera was put into use, and in 1932 another was added under the charge of a voluntary observer near Hillswick. After the Polar Year 1932–33 not much photography was done until 1963 when an all-sky camera of modified Alaskan type was set up on behalf of Edinburgh University. This is now operated on every clear night, and at an increased rate as soon as aurora is observed visually.

Although Lerwick is in a good geomagnetic latitude for auroral work, two factors are against it. One is the high winter cloudiness; and the other is

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PLATE I—LERWICK OBSERVATORY FROM THE SOUTH IN 1965

PLATE II—THE MAGNETOGRAPH HOUSE AS IT IS TODAY
Absolute magnetic huts in the centre, and main Observatory buildings on the right.

PLATE III—THE CONSTRUCTION OF THE MAGNETOGRAPH HOUSE IN 1921/2

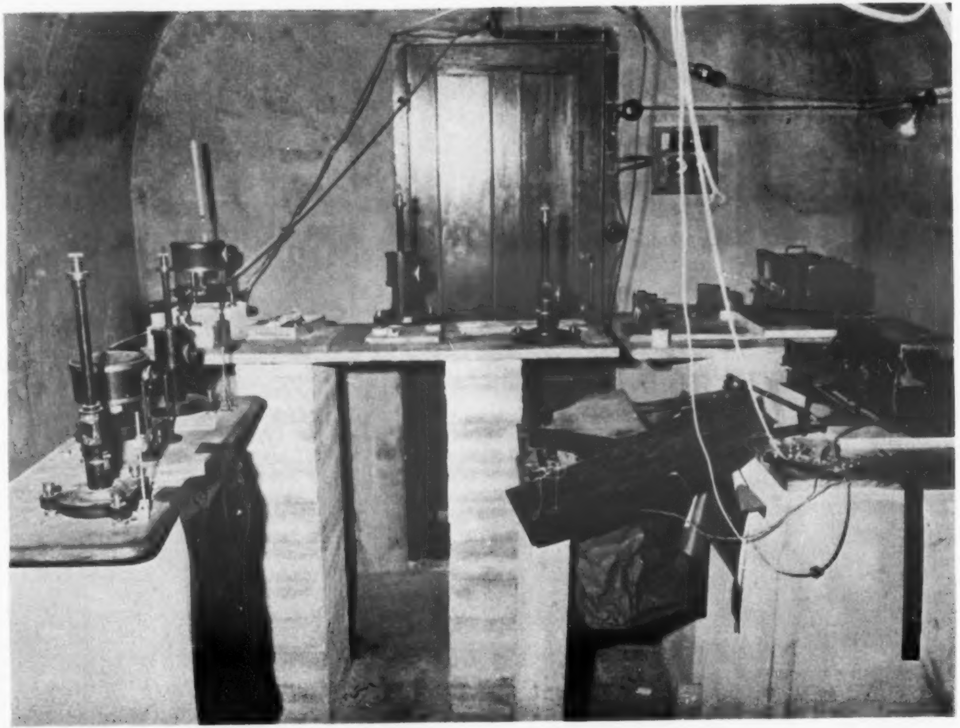

PLATE IV—INTERIOR OF THE MAGNETOGRAPH HOUSE IN 1965

Quick-run La Cour magnetograph nearest camera on left and supplementary (storm) magnetograph beyond.

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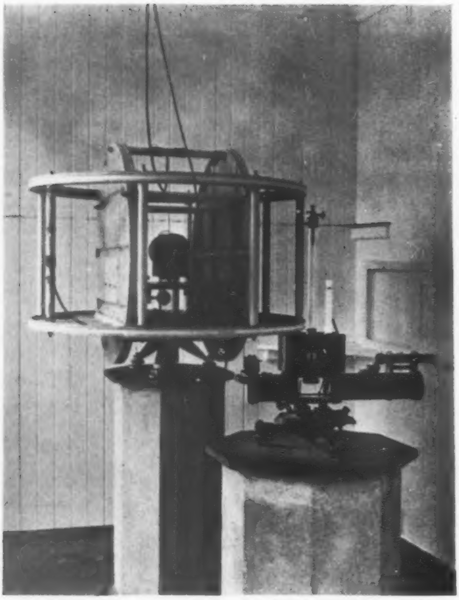

PLATE V—ABSOLUTE MAGNETIC INSTRUMENTS OLD AND NEW

Kew declinometer on near pillar; sensor and bias coils of proton vector magnetometer beyond.

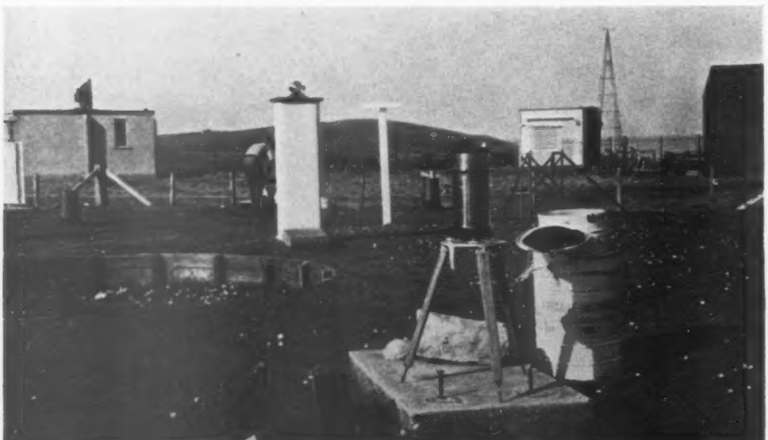

PLATE VI—GRAVIMETER SET UP TEMPORARILY IN THE INSTRUMENT ENCLOSURE IN 1961

In the background on the left the Meteorological Office wind-finding radar (G.L.3), and the balloon-filling shed at centre right.

the increasing brightness in the northern sky due to street lighting in the town of Lerwick. Of recent years, to assist in doubtful cases, observers have had the use of a pair of goggles fitted with interference filters which isolate the yellow-green auroral line.

Meteorology. Initially the Observatory was equipped with quite a comprehensive set of meteorological instruments, and observations were made five times a day. Soon staff shortage caused a reduction and by 1927 there was only one observation a day. The reduction was acceptable because the coastguard station in Lerwick was making and transmitting synoptic observations.

In 1940 Lerwick became a radiosonde station, with flights four times daily, and in 1942 upper wind measurements were added, by direction-finding on the sonde transmission, using two outstations on the north and west of the Shetland mainland. This meant a big increase in staff, many of whom were in RAF uniform. In 1946 wind finding by radar was introduced, enabling the outstations to be closed and staff reduced; and in the last decade automatic-radar-following and automatic reception have made further reductions possible. Launching conditions at Lerwick are often very difficult, and the Lerwick staff are renowned for their skill and zeal in getting the flights away.

Not even during the war did the Observatory become a synoptic reporting station, but in 1945 this came about, because of the closure of the RAF flying stations in Shetland. It then became, and is still, a full 24-hour reporting station.

The weather in Shetland varies a good deal from place to place. The Office has been for many years, and still is, fortunate in its voluntary observers here. At present full climatological stations are maintained at Hamnavoe, Burra, in the west, and at Baltasound, Unst, in the north. In addition there are a number of rainfall stations.

Other activities. It is impossible in the space of this article to describe all the scientific activities which the Observatory has undertaken, but a brief list will be given. Some have been initiated by the Office and others by individual scientists or outside organizations.

Measurement of atmospheric potential gradient began in 1922 with a radium collector and a Dolezalek electrometer, which was replaced in 1925 by a Benndorf electrometer. Other measurements in atmospheric electricity were planned, but insulation in the Lerwick climate was such a problem that they were never begun. In 1930 the safer polonium collectors were introduced, and there was no other important instrumental change until the Benndorf was replaced in 1959 by a valve voltmeter designed at Kew. This has proved very satisfactory and insulation troubles are much reduced. The justification for this long period of recording appeared when decrease of potential gradient at Lerwick in the 1950s gave warning of an unsuspected increase of beta-activity due to nuclear-bomb tests. The importance of Lerwick was that pollution was unlikely to be a complicating factor.[3]

Ozone was first measured using a photographic spectrograph in 1926/27 In 1939 a Dobson spectrophotometer was installed, and measurements were

made intermittently up to 1946. They began again in 1951 and are now made regularly. On selected days the clear air at Lerwick has proved favourable for determining the constants of the instrument.[3,4]

A number of radio investigations have been made at Lerwick, the first being direction-finding and atmospherics experiments in the 1920s. In the 1960s the Radio and Space Research Station had their own staff at the Observatory, and operated an ionosonde and a neutron monitor.

Recording of solar radiation began in 1951, and now global and diffuse short-wave radiation, illumination, and radiation balance are recorded continuously. Many investigations of the relations between the elements have been made, but have not been published. Two articles, on some anomalies in the measurements, have appeared.[5,6]

Varied air-sampling work has been done, beginning with smoke concentration in 1948. Chemical sampling of air and rain began in 1958, and 'enormous quantities' of salts were collected. In January 1958 the total was 36 grammes per square metre of ground. Lista, an exposed station on the Norwegian coast, hardly collects as much in a year.[7] Sampling of air and rain-water for the Atomic Energy Research Establishment, Harwell, started in 1962. Sampling of carbon dioxide for isotopic composition began in 1967, and the last addition was sulphur-dioxide sampling in 1969. All these activities have continued to the present.

The Observatory has always made its facilities available to visiting scientists, from whatever discipline, who wished to make measurements in Shetland. Such visits help to keep the staff in contact with the wider scientific world and are much appreciated. Plate VI shows a gravimeter set up temporarily in the enclosure in 1961. In recent years French scientists have visited Lerwick and made measurements of high-frequency magnetic pulsations. In this case Lerwick was part of a network stretching from Tromsö to Addis Ababa.

Publication of results. For many years the main vehicle was the *Observatories' Year Book,* in which all the Lerwick results were published together.* These year books also contain interesting accounts of the techniques used, and photographs of the site and buildings at different times. The International Geophysical Year (1958/59) began a tendency for collection of each type of measurement in international data centres, which has continued. The *Observatories' Year Book* is no longer published. The final volume of the series was that for 1967 and it contains details of where the data are to be published in future.

Life at the Observatory. In early years conditions were rigorous, especially for those from the south, though generally enjoyable. Today the Observatory has most of the modern amenities. Town water arrived in 1943. The first mains electricity also came during the war years, but it was a small supply for essential scientific purposes only, and not too reliable. In 1945 oil lamps were finally banished, but the electricity supply was only adequate for lighting. Abundant mains power from the public supply did not arrive until 1952. After many years of 'making do', a new office building was put up in 1961, and five houses in 1962. The new houses are more spacious than the

* London, Meteorological Office. *Observatories' Year Book.*

old, but do not resist the Shetland weather as effectively as the 'artisans cheap dwellings' of 60 years ago, which still give good service. By winter 1962, the whole station had oil-fired heating from a central plant.

Despite its inconveniences, life in Shetland is often well liked by those who work here. Many local staff are employed, while others marry local girls and settle down. In time we come to regard the Observatory with affection. In the past three years, three previous Superintendents have visited us while on holiday in Shetland, and all expressed nostalgia for their time here.

The writer thanks the many past and present members of the Observatory staff who have helped him with information, both written and verbal, for use in this article.

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551.593. 53

NOCTILUCENT CLOUDS OVER WESTERN EUROPE DURING 1970

By J. PATON
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Table I contains a summary of observations of noctilucent clouds (NLC) made at stations in western Europe in 1970 during the period from late May to early August when these clouds normally appear. On nights when tropospheric clouds hinder observation so that no reliable conclusion can be reached as to the presence or absence of NLC, 'Cloudy' is entered in the third column. On nights when the sky is clear at a number of stations and no trace of NLC is detectable, 'No NLC' is entered in the third column.

When NLC are observed, the periods of time, in Universal Time (UT), during which they remain visible are given in the second column and notes on the characteristics of the display in the third. Observations of the extent of the display (maximum elevation above the northern horizon and limiting azimuths) seen from selected stations at stated times are given in the remaining four columns. The latitude and longitude of the observing stations are given to the nearest half degree.

In the case of faint displays, it is often difficult to be certain that what is observed is actually NLC. If, in these circumstances, a report of suspected NLC is received from one station only, when other stations with favourable observing conditions are reporting no NLC, it is assumed that the occurrence is doubtful and the report is disregarded.

TABLE I—DISPLAYS OF NOCTILUCENT CLOUDS OVER WESTERN EUROPE DURING 1970

Date — night of	Times UT	Notes	Station position	Time UT	Max. elev. (degrees)	Limiting azimuths (degrees)
26–27 May	2245–0115	Faint bands seen from northern England before dawn.	55·5°N 1·5°W	0115	15	045–090
27–28		No NLC				
28–29		No NLC				
29–30		No NLC				
30–31		No NLC				
31 May–1 June		No NLC				
1–2 June		Cloudy				
2–3		No NLC				
3–4		No NLC				
4–5		No NLC				
5–6		No NLC				
6–7		No NLC				
7–8		No NLC				
8–9		No NLC				
9–10		No NLC				
10–11		Cloudy				
11–12	2115–0115	Cloudy over the British Isles. Fine display of bluish-white and greenish-white bands seen during whole night from Copenhagen, mainly in the north-east segment of the sky. Billows and whirls seen around midnight.	55·5°N 12·5°E	2350 0015	70 90	000–090
12–13		No NLC				
13–14		No NLC				
14–15	2335–0050	Cloudy over the British Isles. Faint display seen from Copenhagen extending sometimes in narrow thread-like bands to the zenith, with amorphous surfaces nearer the northern horizon.	55·5°N 12·5°E	0005 0035	90 90	
15–16	2325–0050	Cloudy over British Isles. Faint veil and greenish bands, with increase in brightness around midnight and 0025 UT seen from Copenhagen.				
16–17	0035	No NLC seen from British Isles. Bright short-lived display reported from Copenhagen.				
17–18	2130–2305	No NLC seen from British Isles. Faint bands seen from Bornholm, Denmark.	55°N 15°E	2305	7	
18–19		No NLC				
19–20		No NLC				
20–21		No NLC				
21–22		No NLC				
22–23		No NLC				
23–24		Cloudy				
24–25		No NLC				
25–26	2310–0020	Faint bands observed in central and southern England.	53·5°N 0° 51°N 4°W	2310 0020	5 20	350 350–010
26–27		Cloudy				
27–28	2340–0134	Single bright band seen close to horizon from three stations in the only region where skies clear. Bright at first; later broke into three patches and became faint.	53·5°N 3°W 53°N 1·5°W 53°N 2·5°W	2340 2355 0110 0125 0134	1 2·5 5 3·5 3·5	350–030 300 010–020 007–013 007
28–29		Cloudy				
29–30	0135–0240	Faint bands appeared in later part of night.	55°N 4·5°W 51·5°N 2°W	0135 0220 0240	8 12 15	000–025 060–110 070–120
30 June–1 July		No NLC				
1–2 July	0205–0240	Faint bands seen from southern England. Cloudy elsewhere.	51·5°N 2°W	0205	12	000–050
2–3		No NLC				
3–4		Cloudy				
4–5		No NLC				
5–6		Cloudy				
6–7		Cloudy				
7–8		No NLC				
8–9		No NLC				
9–10	2215–2340	Faint bands and billows with occasional whirls seen only during the earlier part of night. Southern border at about latitude 59°N.	57°N 2°W 56·5°N 3°W 56°N 3°W 53·5°N 3°W	2240 2300 2311 2305 2330 2241	19 17 18 12 6 5	035–060 035–055 035–055 050–065 000–025

TABLE I—*continued*

Date — night of	Times UT	Notes	Station position	Time UT	Max. elev. *degrees*	Limiting azimuths *degrees*
10–11	2135–2330	Cloudy over the British Isles. Moderately bright bands seen from Denmark until 2330 UT when they were obscured by low cloud.	56°N 10°E	2140	23	340–020
			56°N 12·5°E	2325	10	
11–12	2135–2145	NLC seen from Denmark through temporary break in low cloud.	56°N 10°E	2135	18	340
12–13		Cloudy				
13–14		No NLC				
14–15	2345–0230	Bands, tinted blue or green in places.	55·5°N 4·5°W	2345	8	320–350
				0025	8	310–040
				0120	7	310–010
			54°N 1·5°W	0052	3	030
			53°N 1·5°W	0230	33	350–020
15–16		Cloudy				
16–17		No NLC				
17–18		Cloudy				
18–19		Cloudy				
19–20		Cloudy				
20–21		Cloudy				
21–22		No NLC				
22–23		Cloudy				
23–24	2230	Single band seen close to northern horizon from Unst, Shetland.	61°N 1°W			
24–25		Cloudy				
25–26		No NLC				
26–27		No NLC				
27–28		Cloudy				
28–29		No NLC				
29–30		Cloudy				
30–31		Cloudy				
31 July–1 Aug.		No NLC				
1–2 Aug.		No NLC				
2–3		No NLC				
3–4		No NLC				
4–5		No NLC				
5–6		No NLC				

The clouds were observed on only 15 nights during 1970; they were reported on over 20 nights during the previous six summers, the maximum frequency being 33 nights during 1967. The date of first appearance, 26–27 May, equals the earliest that NLC have been seen from Scotland; they were seen on this date also in 1889 and 1890 (from Ben Nevis Observatory) and in 1960. As in previous years, the clouds receded northwards at the end of the observing season, the last observation, a band close to the northern horizon, being made on 23–24 July from Unst, the most northerly island in the Shetlands. This northwards recession of the clouds probably indicates that the temperature at the mesopause in middle latitudes has now begun to increase from its normal summer minimum. This occurred early during the summers of 1969[1] and 1970. Normally, the last observation from the British Isles is recorded in early to mid-August.

A large number of reports were received of suspected NLC, observed between 2300 and 2330 UT on the night of 4–5 June. Some observers sent photographs and sketches showing a roughly circular patch, and the bearings given from the different stations indicated that it was situated to the west of Scotland. Inquiry at the Meteorological Office, Bracknell, confirmed that what was seen was an ejection of barium at a height of 156 km from a rocket launched from South Uist.

The assistance of the large number of observers who, by providing visual observations, photographs and sketches, have made this analysis possible, is gratefully acknowledged. These synoptic studies are continuing and we

invite the co-operation of observers who may be prepared to contribute to them. Notes on observation of NLC appeared in the *Meteorological Magazine*, June 1967.[2] Observations made in western Europe should be sent to the Balfour Stewart Laboratory, University of Edinburgh, Drummond Street, Edinburgh EH8 9UA, Scotland.

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551.577.36

THE AVERAGE ANNUAL FREQUENCY OF DAILY RAINFALL AMOUNTS

By A. B. THOMSON

Summary. A method is described for obtaining an estimate of the average annual frequency for a station in the United Kingdom of a specified daily fall of rain, and an example is given of the use of the method.

The method uses the relationship $\log y = ar + c$, where y is the average per year of the integrated frequency of daily rainfall amount r, and specimen graphs are shown.

The constant a is inversely proportional to the average daily rainfall and the pattern of the constant of proportionality is shown for the United Kingdom.

The constant c is found by inserting in the equation the value of a for the selected station, and a value of y for daily rainfall amount of 0·40 inch. For stations in the United Kingdom this value of y is given by $R - 10{\cdot}69$, where R is the average annual rainfall in inches for the period 1916–50.

Historical. The annual number of 'rain days', 0·01 inch (0·2 mm) or more, has been published since the earliest volumes of *British Rainfall*[1] and the number of 'wet days', 0·04 inch (1·0 mm) or more, has appeared since 1920. Monthly averages of rain days and of wet days for the period 1916–50 are given in the 1959/60 volume of *British Rainfall* while maps, based on monthly averages, for the period 1901–30, of rain days are published in the *Climatological atlas of the British Isles*.[2] In the same publication there is a map showing the annual frequency of very wet days, 0·40 inch (10 mm) or more.

Glasspoole[3] in 1926 made a critical study of the annual frequency of rain days and of wet days for the period 1881–1915. He produced a map showing the distribution of rain days based on the records from 300 stations in the British Isles. In 1928 Glasspoole[4] published maps of the average number of rain days during each month of the year for the period 1881–1915.

Sowerby Wallis[5] in 1902, using records made at Camden Square, London, over the period 1858–1902 and Dunbar[6] in 1932, utilizing data from Kilmarnock, Ayrshire, for the period 1902–30 examined the fluctuations of daily rainfall, i.e. the amounts within specified limits. In 1932 Bilham and Lloyd[7] widened the scope of the problem by studying the fluctuations at 24 stations scattered throughout the British Isles, and they produced statistics and graphs which gave an indication of the probability of occurrence of a specific daily rainfall amount in the various regions of the British Isles during the four seasons of the year.

The Kilmarnock data published by Dunbar were re-examined by Brooks and Carruthers[8] who showed that the logarithms of the 'integrated' frequencies of the daily rainfalls (i.e. the number of days with 0·01 inch or more, 0·02 inch or more, etc.) when plotted against the daily rainfall lie on a straight line except for the very small and the very large amounts.

Aim of the investigation. In areas having a good network of rain-gauges there are usually several gauges sufficiently accessible to be read daily, thus providing data for processing to supply the needs of planners, engineers, contractors and others whose work depends on a knowledge of the frequency of specific daily falls of rain. Some regions, however, have only a few rain-gauges, none of them read daily, while other parts, particularly in the uplands, have no gauges at all.

This investigation, the results of which are set out below, was undertaken in the hope that an analysis of the existing daily rainfall data would provide an empirical method of estimating the frequencies of daily rainfalls in areas with inadequate information. It must be stressed that the method should not be used for rainfall events rarer than once a year.

Method. From the findings of Brooks and Carruthers in their analysis of the Kilmarnock data, it seemed possible that the straight line

$$\log y = ar + c, \qquad \ldots (1)$$

where y is the average per year of the integrated frequency of the daily rainfalls r, would give an acceptable fit to the data, the intercept c on the y axis and a, the slope of the line, having values relevant to a particular locality. The value of a will be negative.

The daily rainfall data for the period 1916–50 for each of about 100 stations* were plotted on graphs with r as abscissa and $\log y$ as ordinate.† A straight line was then drawn, by eye, among the points. It was found that, in all cases, the integrated frequencies lay on straight lines except that in some the frequencies of the small amounts less than 0·08 inch (2 mm) were underestimated. The extreme (high) values of r, as would be expected from the smallness of their frequency, showed divergence from the general pattern of the intermediate values of r. The straight lines gave a good representation over a large and important range of the daily rainfall values. To most users, the frequency of days with small amounts are of little practical consequence, while the very high values are best treated by an extreme-value technique such as the Gumbel[9] method.

The graphs of eight places scattered throughout Great Britain and Northern Ireland are reproduced as illustration in Figure 1. They are typical of the graphs for the other stations.

It should be noted that the first point plotted (at 0·01 inch) on each graph is the logarithm of the frequency of days with 0·005 inch or more (i.e. measurable rain) and that the straight lines do not cut the $\log y$ axis at a point which indicates the logarithm of the total number of days in the year.

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* London, Meteorological Office. *Hydrological Memoranda.* (Unpublished, copies available in the Meteorological Office Library, Bracknell.)

† For convenience of reference to the older data the graphs have been constructed for rainfall measurements in inches.

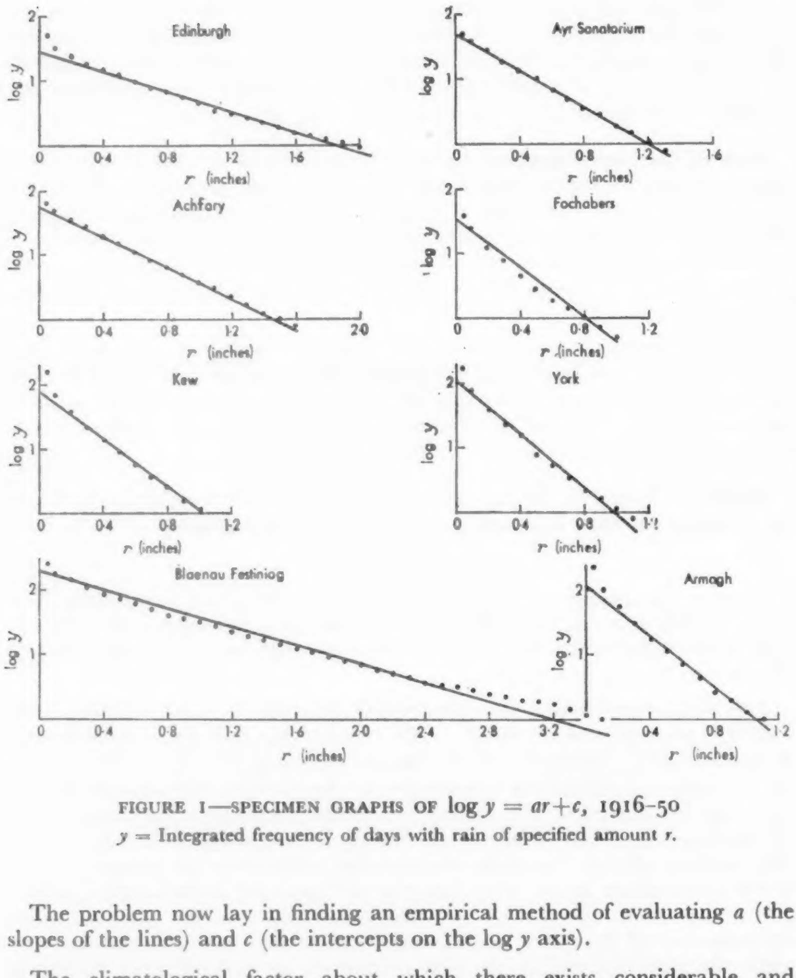

FIGURE 1—SPECIMEN GRAPHS OF $\log y = ar+c$, 1916–50

y = Integrated frequency of days with rain of specified amount r.

The problem now lay in finding an empirical method of evaluating a (the slopes of the lines) and c (the intercepts on the $\log y$ axis).

The climatological factor about which there exists considerable and reasonably accurate knowledge is the annual average rainfall, and reliable estimates can be read off the map[10] for Great Britain on the scale 1:625 000 (approximately 10 miles to 1 inch) published by the Director-General of the Ordnance Survey for the period 1916–50. An annual average rainfall map is also available for Northern Ireland.[11]

It was decided, therefore, to try to relate the parameters determining the daily frequencies at a place to its annual average rainfall.

Evaluation of slope, a. An inspection of the graphs suggested that the slope, a, would be related inversely to the rainfall for the station. The value

$$b = ar_m, \qquad \ldots (2)$$

where r_m is the mean daily rainfall (i.e. $R/365$, R being the annual average rainfall), was worked out for each station, and then the values then mapped (Figure 2). It will be seen that the values of b show a well-defined pattern, b being in general small in the south and east and larger towards the west and north. The pattern is such that the value of b can be read from the map with a reasonable degree of accuracy for any particular locality, thus providing a means of obtaining a, the slope of the line.

FIGURE 2—VALUES OF 100 × b (NEGATIVE)

Evaluation of intercept, *c*. In the *Climatological atlas of the British Isles*[2] a map is published showing the frequencies over the country of days with 0·40 inch (10 mm) or more of rain, and it is stated therein that the frequency for any particular place is very nearly represented by $(R-8)$, where R is its annual average rainfall in inches for the period 1901–30. This relationship was re-examined by using all the stations in Great Britain and Northern Ireland, numbering about 100, for which frequency data for the period 1916–50 are available.[9] The average annual frequencies, $y_{0\cdot40}$, of days with 0·40 inch (10 mm) or more were plotted (see Figure 3) against the average annual rainfalls, R inches, and the average relationship for the 100 stations was found to be the straight line, fitted by least squares,

$$y_{0\cdot40} = 1{\cdot}00R - 10{\cdot}69. \qquad \ldots (3)$$

The scatter was surprisingly small, the correlation coefficient being 0·99.

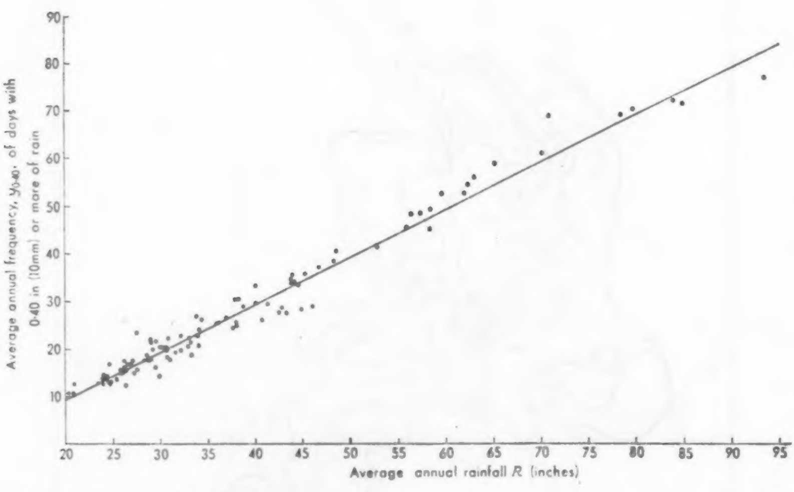

FIGURE 3—AVERAGE ANNUAL FREQUENCY OF DAYS WITH 0·4 INCH PLOTTED AGAINST AVERAGE ANNUAL RAINFALL, 1916–50

$$y_{0\cdot40} = R - 10{\cdot}7.$$

This relationship could now be used to find $y_{0\cdot40}$, i.e. the average annual frequency of days with 0·40 inch (10 mm) or more, for any particular locality whose average annual rainfall is known.

This frequency value, in turn, could be substituted for y in equation (1) to find the value of c appropriate to that frequency at the locality selected. Thus, as $b = ar_m$, equation (1) can be written

$$\log y = \frac{br}{r_m} + c. \qquad \ldots (4)$$

As b, r_m and c could now be ascertained for any locality, the integrated frequency, y, of any required daily rainfall, r, could be found.

It should be noted that, putting $\log y = 0$, i.e. $y = 1$, the intercept $(-cr_m/b)$ on the r axis is the value of r reached or exceeded once per annum.

Example.

Locality : Near Dundee, Nat. Grid Ref. NO (37) 420300

Rainfall : Average annual $(R) = 31$ inches

r_m (mean daily) $= 0{\cdot}085$ inch

b (from Figure 2) $= -0{\cdot}16$ and therefore $a = -1{\cdot}882$.

Frequency of days with 0·40 inch or more from equation (3) is :

$$y_{0\cdot40} = R - 10{\cdot}7 = 20{\cdot}3 \quad (\log 20{\cdot}3 = 1{\cdot}307).$$

Substituting in equation (4)

$$\log y = \frac{br}{r_m} + c,$$

$$1{\cdot}307 = \frac{-0{\cdot}16 \times 0{\cdot}40}{0{\cdot}085} + c, \quad \therefore c = 2{\cdot}060.$$

Thus $\log y = -1{\cdot}882r + 2{\cdot}060$ and this expression gives the integrated frequencies (y) for any daily amount (r inches or more).

The 'once per annum value' of r is

$$\frac{-cr_m}{b} = \frac{-2{\cdot}060 \times 0{\cdot}085}{-0{\cdot}16} = 1{\cdot}09 \text{ inches.}$$

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551.553.21:551.465.5

EARLY REVERSAL OF THE INDIAN OCEAN CIRCULATION IN 1956

By P. B. WRIGHT

The sudden changes in the tropospheric circulation patterns over the Indian Ocean and adjacent areas accompanying the onset of the Indian south-west monsoon in May and June have been described by Wright.[1] In an extension

of the study (Wright and Stubbs[2]) it was shown that the effect of the changes was widespread, extending well into the Pacific and involving a net mass flux out of the northern hemisphere. Evidence for these conclusions was provided by the fact that in 1956 all the changes occurred about a month earlier than usual.

It is known that the sea surface currents in the Indian Ocean undergo a reversal of direction about the same time of the year. Rochford[3] showed that the current off the coast of Western Australia participates in this reversal. Evidence for this included an analysis of the variations in sea surface salinity off Rottnest Island (32°S 115½°E) during 1951–57. His Figure 1, reproduced here, shows that the salinity normally changes rapidly from a high value during January to April, associated with a current from the south, to a low value during June to September, associated with a current from the north.

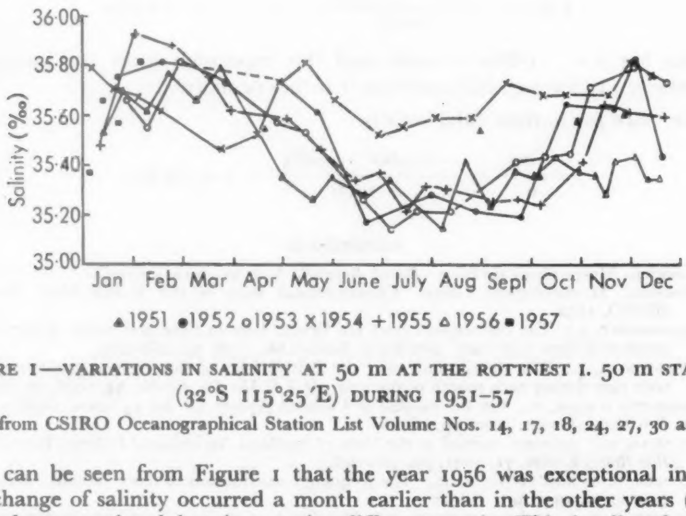

FIGURE 1—VARIATIONS IN SALINITY AT 50 m AT THE ROTTNEST I. 50 m STATION (32°S 115°25′E) DURING 1951–57

Data from CSIRO Oceanographical Station List Volume Nos. 14, 17, 18, 24, 27, 30 and 33.

It can be seen from Figure 1 that the year 1956 was exceptional in that the change of salinity occurred a month earlier than in the other years (1954 was also exceptional but in a quite different way). This implies that the reversal of the current also occurred a month early in 1956. This evidence points strongly to the conclusion that the reversal of the surface circulation of the Indian Ocean is closely linked with the changes in the atmospheric circulation.

The author is indebted to Dr D. J. Rochford for permission to reproduce his diagram.

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REVIEW

Process and method in Canadian geography, Weather and climate, selected readings, **edited by J. G. Nelson, M. J. Chambers and R. E. Chambers. 225 mm × 150 mm, pp. x+420, *illus.*, Methuen and Co. Ltd, 11 New Fetter Lane, London, EC4, 1970. Price: £3·50.**

This is not a textbook on *weather and climate* but a collection of papers on *weather and climate and the human economy,* and deals mainly with agrometeorological and hydrological problems. Because of the wealth of excellent material available, the selection is 'somewhat arbitrary'. The papers illustrate research techniques and methods of analysis and the study of processes, with special reference to the Canadian scene; and they provide important primary source material for research and study in Canadian geography. Some papers are reviews or partly so. The original bibliographies have been retained because these are regarded as important to readers wishing to follow up research problems.

There are articles on the Arctic circulation, the location of the Arctic front and upper air features over the Canadian dry belt. Other topics discussed are: drought indicators, soil moisture under crop and fallow surfaces, moisture deficit, latent evaporation and evapotranspiration, precipitation and the moisture budget, drought patterns in the prairies and precipitation variations in a forested watershed. Problems peculiar to cold regions are especially stressed in papers on the forecasting of ice conditions, evaporation from snow cover, and the thermal régimes of permafrost under various types of vegetation.

Further interesting articles deal with the distribution and causes of hail, Chinook winds and their influence on snow cover, climatic changes in Canada over the last 14 000 years and climatic trends on the prairies during the last 100 years. Other papers discuss the concept of heat units and crop growth, and the variation of temperature with latitude, longitude and altitude. Agroclimatological relationships, in general, and the subject of human response to weather and climate are reviewed. Special instrumentation problems concern the measurement of lake surface temperatures by aerial survey, the study of ice formation on the Niagara River, and soil-moisture sampling grids.

The book does not include any articles on urban climate, as was originally intended, though the urban heat-island effect is suggested as a possible cause of a downwind area of maximum hail duration. A section on the impact of urbanization and industrialization on surrounding agriculture and forestry would have been a useful and appropriate addition to this volume. As this volume includes several papers relevant to topics which form the subject of future books in the series, care will be needed in the later books to avoid excessive overlap.

The presentation of *Weather and climate* could be improved by making the diagrams more complete and self-contained. The inclusion of a physical map of the Canada region, for general reference, would be especially helpful to non-Canadian readers. It is questionable whether 9 pages of information on 'degree-days' and 12 pages of maps of temperature deviation can be justified.

The book should prove extremely useful to members of related disciplines and research workers in interdisciplinary fields. It is aimed to help at various academic levels: namely the new student, more advanced undergraduates in meteorology and related courses, and graduates concerned with recent developments in research. The first two groups of readers, at least, would expect to borrow a copy of the book from a library.

E. N. LAWRENCE

NOTES AND NEWS

Retirement of Mr A. A. Worthington, O.B.E.

Mr Arthur Agnew Worthington joined the Office as a Technical Officer in 1939 and spent most of the war years providing forecasts covering long routes for aircraft of Coastal and Transport Commands. He was mobilized as a Flight Lieutenant in 1943 and following his release from the RAFVR in 1946 spent the next three years in Malta.

Early in 1950 he was promoted to Principal Scientific Officer and was posted to Prestwick where he spent nearly eight years as a Senior Forecaster.

In late 1957 Mr Worthington was posted from Prestwick to Headquarters where, over the course of the next nine years, he dealt with meteorological matters connected with civil aviation and played a major part in many international meteorological arrangements including the setting up of the ICAO Area Forecast System. In 1966 he was promoted to Senior Principal Scientific Officer and took charge of the Telecommunications Branch of the Office.

Arthur Worthington has always been a great believer in the 'eyeball to eyeball' confrontation method of decision making and in the post of Assistant Director in charge of meteorological telecommunications has been able to use this working technique to full advantage in planning and organizing the Office's new telecommunications system. He retired on 3 May 1971 and so remained in his post long enough to see his plans begin to come to fruition. He was appointed an Officer of the Order of the British Empire in the New Year's Honours List this year.

Arthur's indefatigable energy will now, I understand, be turned to his life-long love of music for which he has had little time in the last few years. He plans to put to serious purpose his competence as a church organist.

All his colleagues wish Arthur and his wife many happy years of retirement.

V. R. COLES

LETTER TO THE EDITOR

517.512.2

Introduction to the Fast Fourier Transform (FFT) in the production of spectra

I have read with interest the article 'Introduction to the Fast Fourier Transform (FFT) in the production of spectra' by R. Rayment.* In connection with this it may be of interest to readers to know that the Meteorological

* RAYMENT, R.; Introduction to the Fast Fourier Transform (FFT) in the production of spectra. *Met Mag, London*, **99**, 1970, pp. 261–270.

Research Flight, Farnborough, has a programme incorporating the FFT technique written in ICL 1900 FORTRAN. The programme has been developed primarily for, but is not restricted to, the analysis of data collected by MRF aircraft. On the ICL 1907 computer the programme occupies just under 20K words of core store with $3N+10$ real variables being required for data handling (N = number of data points). Up to six channels of data may be handled simultaneously giving full or part cross spectral analysis according to the user's requirements. The core store requirement is not affected by the number of data channels supplied. The programme includes automatic plotting routines which present the main outputs on convenient log $\times$ log and log $\times$ linear scales.

The output from the programme consists of two main sets of results :

(i) $N/2$ smoothed spectral estimates for each data channel supplied.

(ii) $N/2$ corresponding values of $S_{xy}(n)$, $Q_{xy}(n)$ as described by Mr Rayment; and three further cross spectral quantities derived from these after averaging, namely : cross spectral amplitude $SA_{xy}(n)$, phase angle $PHI_{xy}(n)$ and coherence $COH_{xy}(n)$.

Further details may be supplied on application to Meteorological Research Flight, Farnborough.

Meteorological Research Flight, Farnborough P. R. COCKRELL

OFFICIAL PUBLICATIONS

Scientific Paper

No. 32. The Bushby-Timpson 10-level model on a fine mesh. By G. R. R. Benwell, M.A., A. J. Gadd, Ph.D., J. F. Keers, B.Sc., Margaret S. Timpson, B.Sc. and P. W. White, Ph.D.

A full description is given in this paper of the 10-level numerical weather prediction model which has been developed during the past few years by the Forecasting Research Branch of the Meteorological Office for use in investigating the dynamics of fronts and in predicting frontal rainfall. The basic model as originally proposed treated a considerably idealized atmosphere, but the formulation now includes representations of the effects of surface friction, topography, surface exchanges of sensible and latent heat, sub-grid-scale convection, and lateral diffusion. Considerable improvements have also been made in the method by which initial wind fields are obtained for the model.

The model is still undergoing development; this paper describes the stages of the development up to the end of 1969, and an example of a recently computed forecast is included.

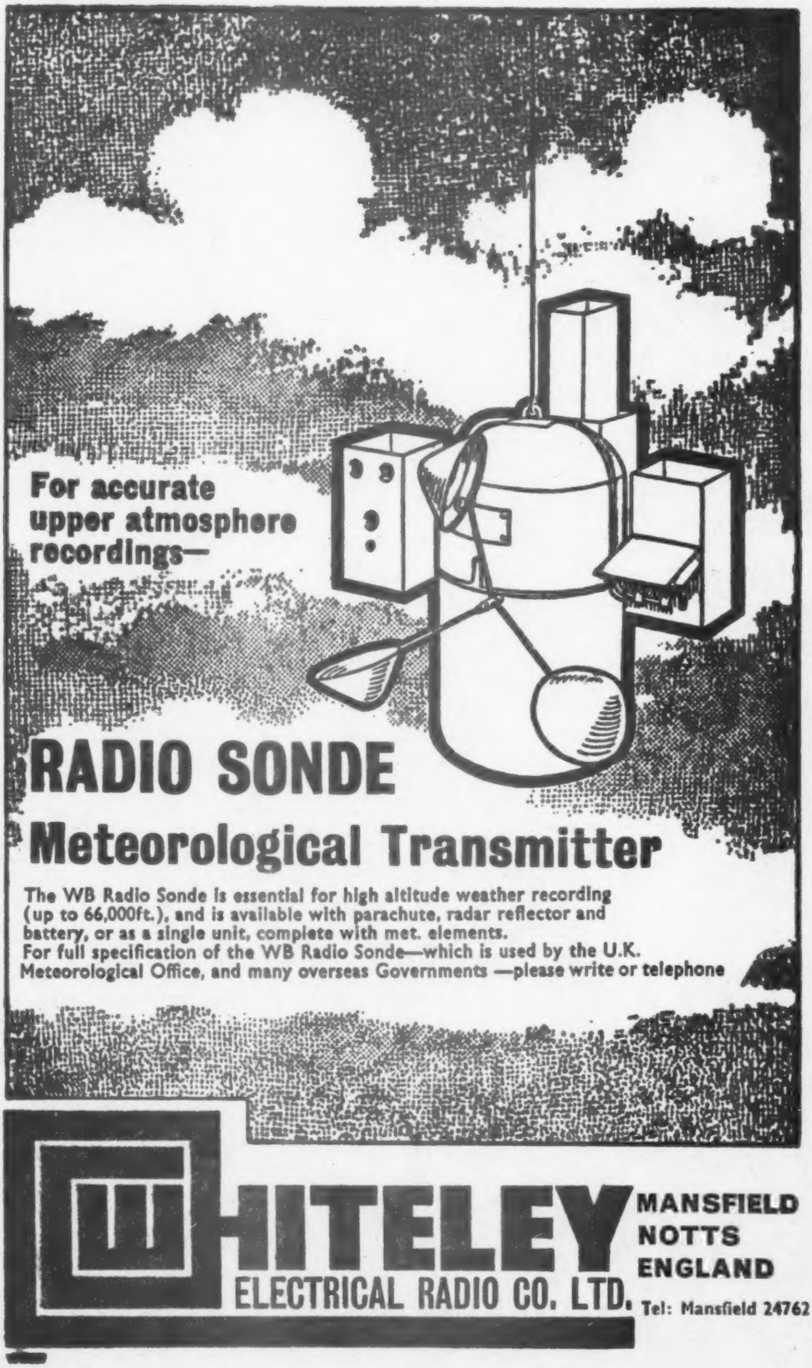
The following publication has recently been issued : *The practice of weather forecasting*. By P. G. Wickham.

Modern weather forecasting is a mixture of electronic computations and human judgement. This book is concerned with the latter, and it was written mainly for young professional forecasters. However, no reader who has a

modest grounding in elementary meteorology and who wishes to find out how weather maps are used in day-to-day forecasting need be deterred by it. The discussion is, throughout, entirely simple and non-mathematical and the text is copiously illustrated by weather maps.

The early chapters are each devoted to particular weather elements, such as wind, temperature, clouds, and the analysis of these elements is discussed in some detail. In later chapters the principles of forecasting are described and some cameo sketches of forecasters thinking aloud as they work are included.

To round off the book and bring the discussion into perspective, a brief description is included of the place of computers in the large weather forecasting organizations of today. There is also a glimpse at how this partnership of man and computer may develop in the future, but it is the human half of the partnership that is the principal subject matter of the book.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